Final Report for Microwave Emission from Polar Surfaces 1

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13. Abstract - The goal of the work performed on this grant was to investigate the passive microwave signatures of arctic sea ice concentrating on new, young, and mature first-year ice types to determine the extent to which passive microwave remote sensing of the polar regions can be used to determine sea ice concentration and ice type. A series of surface based observational studies was carried out in the Arctic and at the Cold Regions Research and Engineering Laboratory in Hanover NH. These studies involved the acquisition of microwave and infrared brightness temperatures and emissivities of sea ice during various stages of development, in particular those of importance for the energy balance of the polar regions. We determined that it is possible to distinguish between growing congelation ice (laminar growth) and frazil pancake ice (growth in a wave field). The following categories have distinct microwave signatures identifiable under favorable conditions from satellite - open water, new congelation ice, frazil ice, young congelation ice, pancake ice, and first-year ice. Concurrent theoretical modeling to relate the ice emissivities to the physical properties of the ice was successful in reproducing the signature development of these ice types consistent with the measured physical properties.

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MICROWAVE EMISSION FROM POLAR SURFACES

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Long Term Goals

Our long term goals on this project are to understand the relationship between the microwave emission and scattering properties of sea ice and its physical, structural, and optical properties from initial formation through seasonal cycling to final decay. We have used this information to estimate how well multifrequency multipolarization passive microwave satellite data, alone and in conjunction with available satellite data from other sensors, can be applied most effectively to identify the spatial and temporal distribution of the different types and ages of sea ice.

Scientific Objectives

Our objective has been to investigate the temporal dependence of the microwave and thermal infrared signatures of sea ice types less than 1 year old because of their importance for the regional energy balance and dynamical behavior of the ice covered oceans. We are particularly interested in understanding the dependence of the emissivity spectrum on (1) the growth of thin congelation and frazil/pancake ice, (2) the deposition/formation of snow and frost flowers (with emphasis on the transition from young ice to first-year ice), and (3) first-year pressure ridge formation and aging.

Approach

Our core observations consisted of surface based measurements of brightness temperature (T_B) and emissivity at microwave frequencies of 6.7, 10, 18.7, 37, 90 GHz for vertical and horizontal polarization (V-Pol & H-Pol) and in the thermal infrared (8-14μm band). Angular scans were carried out from 30-70° nadir angle, and spatial scans at 50° nadir angle were made over distances of 10's of meters at 1 to 2 meter resolution.

Our approach was to determine the evolution of the microwave and thermal infrared signatures of new and young ice, mature first-year ice and pressure ridges in cooperative experiments where the physical properties of the ice were measured concurrently. During the last 3 years we have investigated (1) the early growth phases of congelation and pancake ice, (2) the transition from new to young to first-year ice, and (3) the relative importance of the near surface layers for ice with a rough surface and/or a snow cover. We have also investigated the full polarimetric signatures of a wide variety of ice types at selected microwave frequencies to look for azimuthal anisotropies in the surface layers which might improve the ability to distinguish among sea ice types.

To interpret the influence of the physical properties on the microwave and infrared signatures we have applied our multilayer strong fluctuation theory (SFT) model for ice emissivity and scattering. We have applied model calculations to observations at selected sites with considerable success and plan to extend the analyses in the coming year. We have

also supplied our observational data to other investigators who have developed their own forward and inverse models.

Tasks Completed

We have completed observational programs during six related field experiments: LEADEX 1992; CRREL 1993, 1994, & 1995; Beaufort & Chukchi Seas 1994; SIMMS 1995. These covered almost all stages of development of new, young, and first-year sea ice. Our programs were carried out in coordination with ice physical properties characterization and in conjunction with concurrent radar, visible, & solar infrared observations.

Results/Conclusions

We found that the passive microwave data from the experiments at CRREL are consistent with field observations for ice of the same salinity, thickness, and snow cover. We have identified the following evolutionary stages & processes with distinct signatures. The signature evolution of early growth phases of thin ice (0 to 5-8 cm) has been well documented. It is characterized by rapid evolution and is sensitive to freezing rate & weather conditions. Bare young ice to bare thin first-year (FY) ice (8-30cm) has a signature which depends on ice temperature but remains quite stable. The transition from young to normal snow-covered FY ice is a result of frost flowers formation or snow deposition followed by metamorphism and brine redistribution in the uppermost layers of the ice.

Our theoretical models have been able to reproduce most features of evolution from OW to young ice and young ice to thick FY ice. We find that proper representation of the ice structure is crucial. In particular, a low density layer of snow or frost flowers is necessary, and brine must be present in bottom of the low density layer. Scattering is not sufficient to explain the transition by itself but some is needed implying that grain metamorphism in the low density layer is important. At present the polarization and gradient ratios are reproduced well but $|T_B|$ values must be modified slightly.

Thermal infrared emissivities in the 8-14 μm band for sea ice lie in the range 0.98 to 0.99+ for almost all cases ($\theta_{nadir} = 50^o$) and the values are consistent with existing model calculations. The emissivities are greater for rough or snow covered ice than for bare thin ice. Values of 0.98 can give an apparent error of about 5°C in T_{surf}.

Fully polarimetric observations of the various ice types studied to date at 10, 37, and 90 GHz show degrees of linear polarization from 2% up to about 25% but negligible values for the 3rd and 4th Stokes parameters. These results have provided direct support of the assumption of azimuthal symmetry central to our SFT model. They also suggest that fully polarimetric observations would not be useful for first-year sea ice type discrimination.

Impact for Science

Our observations have been central to the development and application of thin ice algorithms (Wensnahan, Ph.D. Thesis; D. J. Cavalieri, 1994) and our results show that the potential for satellite imagery is considerable if the spatial resolution of the imagery can be improved. Principal component analysis, for example, has revealed distinct signatures for both new and thin sea ice. Our analyses combining modeling and observation have shown

that current microwave theory (e.g. SFT) appears to reproduce the radiometric signatures of FY ice types quite well using the actual physical structure of the ice.

Relationships to Other Programs or Projects

Our results have been incorporated into an analysis of SSM/I imagery for the Bering Sea ice cover which yields not only the distribution of thin ice but estimates of T_B versus ice thickness and ice age. Using a non-linear thermodynamic model it was also possible to estimate sensible heat exchange with the atmosphere and salt fluxes to the mixed layer.

We are about to begin a detailed comparison of our passive microwave results with visible, infrared, and radar observations. With the help of our radiation models we expect to learn a great deal about how we can improve on existing sea ice algorithms using concurrent combined sensor information.

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Presentations and Briefings:
PIERS Pasadena,CA, 1993,
CRREL Workshop, Hanover, NH, Oct. 1993,
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